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Effect of Wind Speed and Air Temperature on the Durability of PCC Surfaces

تأثير سرعة الريح ودرجة حرارة الهواء على مقاومة سطح الباطون البورتلندي

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Abstract

Durability of Portland Cement concrete (PCC) surfaces is affected by several factors that should be considered in the design and construction of concrete surfaces. Proper curing of fresh concrete surfaces plays a major role in increasing the abrasion resistance and in turns the durability of hardened concrete surface. Factors such as ambient temperature, humidity, and wind speed will also affect the degree of evaporation of surface moisture, which directly affect the curing condition. In this research, the effects of wind speed and ambient temperature on abrasion resistance of Portland Cement concrete surfaces were analyzed based on ASTM C944. Based on the obtained results, the durability of fresh PCC surfaces is significantly affected by wind speed in excess of 60 kph during the setting-time of concrete. Also abrasion resistance is significantly affected by ambient air temperature in excess of 35 °C. In addition, the effect of ambient temperature and wind speed on the durability of PCC is inversely proportional within concrete surface.

Key words: concrete surface, abrasion resistance, durability, wind speed, ambient air temperature.

ملخص

تتـــأثر مقاومـــة ســـطوح البـــاطون البورتلنـــدي بعـــدة عوامـــل، وهـــذه العوامـــل يجـــب أن تؤخـــذ بعـــين الاعتبـــار فـــي مرحلتـــي التـــصميم والإنـــشاء لهـــذه الـــسطوح. إن معالجـــة ســـطح البـــاطون الطـــري تـــساهم بـــدور كبيـــر فـــي قـــدرة الـــسطح علـــى مقاومـــة الإهتـــراء، ممـــا يـــؤدي الـــى زيـــادة مقاومـــة الـــسطح لعوامـــل الطبيعـــة والاســـتعمالات المختلفـــة. ومـــن العوامـــل التـــي تـــؤثر بـــصورة مباشـــرة فـــي ســـطح البـــاطون الطـــري - وذلـــك بنـــاء علـــى تبخـــر المـــاء الـــسطحي - هـــي: درجـــة الحـــرارة الجويـــة، وســـرعة الـــريح، ودرجـــة الرطوبـــة وفـــي هـــذا البحـــث ســـتتم دراســـة تـــأثير كـــل مـــن ســـرعة الـــريح ودرجـــة الحـــرارة الجويـــة علـــى مقاومـــة الاهتـــراء الـــسطحي للبـــاطون البورتلنـــدي. وقـــد تـــم اعتمـــاد طريقـــة الجمعيـــة الأمريكيـــة للفحـــص والمـــواد C944 لفحـــص مقاومـــة الإهتـــراء للظـــروف والمجـــالات المختلفـــة. بنـــاء علـــى النتـــائج المـــستقاة مـــن هـــذا البحـــث، فقـــد تبـــين أن هنـــاك تـــأثيراً مباشـــراً لـــسرعة الـــريح فـــي فتـــرة زمـــن الـــشك الابتـــدائي، وكـــذلك لدرجـــة حـــرارة الجـــو إذا مـــا ارتفعـــت عـــن ٣٥ درجـــة مئويـــة، فهـــذه تـــؤثر فـــي مقاومـــة اهتـــراء الـــسطح. لقـــد تبـــين –أيـــضا- أن كـــلا العـــاملين يـــؤثر فـــي مقاومـــة الـــسطح البورتلنـــدي بـــصورة عكـــسية مـــن خـــلال ســـماكة السطح.

Introduction

Durability of Portland Cement concrete (PCC) surfaces is of great importance, especially in cases of concrete floors subjected to foot traffic, vehicular traffic, forklifts, heavy trucking, all having attrition, scraping, and percussion behavior. Other applications of the nature of attrition, scraping, and cavitations are of abrasive behavior like hydraulic structures, dams, spillways, and tunnels. Several factors affecting the durability of concrete surfaces which should be considered in the design and construction of concrete surfaces to withstand abrasion due to

rubbing and scouring, sliding, impact, scraping, attrition, …etc. The failure of concrete to resist abrasion can be traced to cumulative effect such as soft aggregates, inadequate compaction strength, improper curing or finishing, or over-manipulation of the plastic concrete surface.

Efficient curing increases the abrasion resistance. A correlation of curing time and abrasion resistance reported by Sawyer [(1)] involved a series of tests comprising a wide range of water Cement ratio (W/C) and incremental curing. From this study, it is apparent that marked improvement in abrasion resistance can be expected with extended curing time, especially for surfaces composed of leaner concrete.

The need for taking deliberate steps to ensure proper curing of concrete is dependent on the ambient atmospheric conditions. In certain environments, where the relative humidity and temperature are favorable, no deliberate actions need to be taken to cure the concrete. Usually, conditions are such that some actions are required. Although there are no standard definitions, general ambient conditions could be put into three temperature categories. These are hot, 32 °C and above; cold 10 °C and below, and normal 10-32 °C (2). Within these broad categories, the severity of environment is affected by relative humidity and wind speed. Therefore, by determining the ambient temperature, relative humidity, wind speed, and concrete temperature, the rate of evaporation of water from the exposed surface of fresh concrete could be estimated only in cases where free water exists on the surface. Hot weather conditions are normally considered more damaging to concrete. This is because of the potential drying of concrete at early ages as a result of high temperatures that may be accompanied by low relative humidity and wind.

Research significance

This research was focused on the effect of variables such as ambient air temperature and wind speed on curing of Portland Cement concrete surfaces and in turn on the durability of concrete surfaces. Abrasion resistance is considered one of the measures of durability of concrete surfaces, which tests the ability of those surfaces to withstand all forms of attrition, scraping, percussion, and cavitations. Damage to concrete

surfaces can cause extensive damage to the concrete structure. Issues related to hot weather concreting and determination of ambient air temperature could be better evaluated to give proper attentions to ingredients, production methods, handling, and placing of concrete.

Literature review

The setting process of concrete was the result of chemical reactions between Cement and water. Therefore, the laws of chemical kinetics should be in effect, and it is not surprising to find that those chemical reactions and the setting process are affected by ambient air temperature or wind speed. In general this chemical reaction proceeds faster at high temperatures in presence of water, and in turn presence of water in concrete mix is affected by evaporation by both high temperature and wind speed.

The properties of fresh and hardened concrete are affected by weather conditions. The primary problems in hot weather concreting related to the increased rate of Cement hydration and evaporation of moisture from fresh concrete surface, which both increase the water demand. The increased rate of Cement hydration causes the concrete temperature to rise and slump loss to increase. In addition, setting time will decrease as a result of abnormal weather conditions compared to normal conditions. Quick setting decreases workability during handling, consolidating, and finishing. A major problem with fresh concrete in hot weather is plastic shrinkage, which occurs during curing when the rate of evaporation is greater than the bleeding rate. Cracks developed on the concrete surface because the surface moisture evaporates causing it to dry and shrink before adequate tensile strength is developed. The evaporation rate depends on environmental conditions, especially concrete temperature, air humidity, and wind speed. Water evaporation from the surface will make Cement hydration short of moisture, which limits the ultimate concrete strength.

Laboratory program conducted by the California Division of Highways [(3)] considered the effect on abrasion of such variables as slump, finishing, curing, and surface treatments using linseed oil. Test

data indicated, among these variables, that the greatest abrasion losses encountered were associated with less-than-adequate curing procedures.

Zawde[4] investigated the effect of different environmental conditions on the rate and amount of water evaporation from fresh mortar and concrete surfaces. The variables studied were temperature, initial mortar and concrete temperature, wind speed, relative humidity, type of Cement, and water content (W/C). Zawde found that in hot, humid climate, evaporation is three and a half time lower than in a hot, moderate climate and 7 % times lower than in a hot, dry climate.

Kettle and Sadegzadeh[5] tested the influence of construction procedures on abrasion resistance. A test method, based on rotating steel wheels running in a circular path, has been adapted to assess the abrasion resistance of concrete. Results showed efficient curing significantly increased the abrasion resistance.

Senbetta and Scholer [6] developed a new approach and a new test procedure for making a quantitative assessment of how well concrete was cured. Assessment was based on absorpitivity of the paste and abrasion testing of the surface. The results showed significantly larger changes in absorpitivity of paste between the surface and the bottom regions of poorly cured samples. The abrasion test results were also found to be in agreement with those of the absorpitivity test.

The issue of maximum temperature for hot weather concreting was raised in the America Concrete Institute (ACI) Building Code requirements for placing concrete in tropical climate by users of the ACI documents [7]. Some people specify a maximum permissible concrete temperature of 32°C. Others suggest temperature higher than 32°C is allowable if the concrete contains a set-retarding admixture.

Section 5.13 of ACI 318-02 “Building Code Requirements for Structural Concrete” requires that: “During hot weather, proper attention shall be given to ingredients, production methods, handling, placing, protection, and curing to prevent excessive concrete temperatures or water evaporation that could impair required strength or serviceability of the member or structure” [7-8].

Hot weather applies to a project when a combination of conditions, primarily environmental, adversely affects fresh and hardened concrete properties. The conditions that must be considered are high air temperature, high concrete temperature, low relative humidity, wind exposure, and solar radiation exposure. It is important to note that hot weather concreting can occur in any location at any time a combination of the above condition is present [(9)].

Section R 5.13 of the ACI 318 commentary cites recommendations for hot weather concreting. The document states that: “in the more general types of hot weather construction, it is impractical to recommend a maximum limiting ambient or concrete temperature because circumstances vary widely. A limit would serve a specific cause might be unsatisfactory in others. Accordingly, the committee could only point out the effects of higher temperatures in concrete as mentioned in Section 1.3 and 2.2.1. The committee advised that at some temperature between 24 and 38°C there is a limit that will be found to be most favorable for best results in each hot weather operation, and such a limit should be determined for the work”. ACI 305-99 contains similar recommendations regarding limits on maximum concrete temperature [(9-10)].

In the United States of America most states specify a maximum concrete temperature at placement between approximately 33 to 39°C (85 to 95°F). This limit remains the same irrespective of the type of mineral or chemical admixture used. For example, the Florida Department of Transportation’s hot weather concreting requirements allow a maximum of delivered concrete temperature of 38°C and require the concrete producer to use specialized hot weather mixture proportioning methods [(10)].

Cark, Sumer and Celik (12) tested the effect of curing temperature on compressive strength and water permeability of concrete. The curing temperatures used in this investigation were: 5°C, 22°C, 39°C, and 52°C. The results obtained have shown that as the curing temperature increases, the compressive strength of the specimen increases. On the other hand, as the curing temperature increased up to room temperature, water

permeability of concrete decreased but as the temperature was increased, water permeability started to increase.

Schindler and Mc Cullough [13] investigated the importance of concrete temperature control during concrete pavement construction in hot weather conditions. The research focused on long-term concrete performance and the reason why high concrete temperatures during placement are of concern. The research showed a detrimental long-term concrete performance as a result of high concrete temperature causing an increase in the rate of hydration, thermal stresses, the tendency for drying shrinkage cracking, permeability, and decrease of long-term concrete strength and durability as a result of cracking.

Methodology

For the purposes of this research, several parameters were considered as main variables; amongst which air temperature, wind speed and water-cement ratio. To best simulate the field condition, a closed environment was used which a small room with 40 % fixed humidity. Each application of the variables under consideration including poring and casting were done during the initial set of Portland Cement concrete mixture. The duration of application of the specified wind speed and air temperature was forty five minutes, which is approximately the duration of the initial set of the concrete mixture.

In order to make the essential assessment of the effect of air temperature and wind speed, several sub conditions were considered. For air temperature, four levels were set; 15 °C, 25 °C, 35 °C, and 43 °C all within the range of interest to most countries in the Middle East. For each air temperature value, three applications of wind speeds were used; 35 kph, 60 kph, and 90 kph. To explore the effect of both variables of wind speed and air temperature, three concrete mixes were used with different W/C; of 0.30, 0.45, and 0.60 (designated as M1, M2, and M3, respectively). This brings the total number of conditions tested to thirty six (three specimens for each condition combination), they vary in air temperature, wind speed, and water-Cement ratio values. It is important

to note that each of the thirty-six conditions are prepared and tested separately. This means that each mix (based on W/C) and each condition of wind speed and temperature were done separately.

The measure of durability of Portland Cement concrete surface was abrasion resistance or wear resistance. The Standard Test Method for Abrasion Resistance of Concrete or Mortar surfaces by the Rotating-Cutter Method, ASTM C944 was adapted to measure abrasion resistance. Portland Cement concrete surfaces exposed to different air temperatures and wind speeds would affect the immediate concrete surface. To explore the effect of those variables through the surface thickness, two cases were considered as follows:

Case one: Testing the exposed surface using 20-kg load over the surface using the abrasion cutter-head for a period of two minutes. The purpose of this case is to test the amount of wear or abrasion of each condition relative to the other; this will give an indication of durability of each condition relative to the other.

Case Two: Testing the exposed surface for the second time on the same location tested in case one case to have an assessment of the extent of the effect of the exposure to the two variables considered. This will test the increase or decrease of abrasion resistance through the Portland Cement concrete surface.

ASTM C944 standard requires weighing the specimen before and after testing, this difference indicates the degree of abrasion resistance. Specimens considered were 10x10-cm surface with 5-cm thickness. Heating and cooling were utilized to maintain the required air temperature and an air-blowing machine with potentiometer to control air speed were used to simulate wind speed in the field. Table 1 includes the properties of fine and coarse aggregates used in the concrete mix proportions of Portland Cement concrete constituents used in the mixture are presented in Table 2.

Table (1): Properties of fine and coarse aggregates used in the concrete mix.

	Property	Size groups and percentages (Size mm, %)		
		P1 (19mm, 15%)	**P2 (12.5mm, 18%)**	**P3 (9.5mm, 15%)**
Coarse Aggregate	Bulk specific gravity	2.66	2.62	2.60
	Bulk specific gravity (SSD)	2.82	2.78	2.88
	Apparent specific gravity	2.76	2.77	2.81
	Absorption (%)	1.93	1.62	2.88
	Unit weight (kg/m^3)	1552.6	1516.44	1511.28
	Void content (%)	41.56	41.96	42.0
	Los Angeles test (% Loss)	26.8		
Fine Aggregate		**P3 (4.75mm, 9%)**	**P4 (Sand, 43%)**	
	Unit weight (kg/m3)	2.5	1668	
	Bulk specific gravity	2.88	2.64	
	Void content (%)	42.0	36.7	

Table (2): Concrete constituents proportions

Mix Number		Constituents				W/C %
		Water	**Cement**	**Coarse Aggregate**	**Fine Aggregate**	
M1	kg/m^3	178	593	1063.8	486.6	0.30
M2	kg/m^3	178	395.4	1063.8	653.5	0.45
M3	kg/m^3	178	296.5	1063.8	737	0.60

In order to explore the effect of air temperature and wind speed on specimen's comparative specimens were prepared and tested in a standard curing condition without exposure to any environmental conditions. Considering the exposed and unexposed specimens as well as the two cases tested, the grand total number of specimens tested as apart of this research is two hundred and sixteen specimens (Thirty six condition of testing with three specimen per condition and that of the standard reference condition) and the grand total number of tests to three hundred twenty four (for the two cases of abrasion on the same sample for the thirty six conditions considered).

Results and Discussion

Abrasion resistance was used as a measure of durability in the analysis of the effect of air temperature and wind speed on the curing and durability of Portland Cement concrete surfaces. Figure 1 summarizes the results of case one for the exposed specimens designated as “field specimens” and the standard cured specimens designated as “ideal specimens”. Conditions of ambient air temperature as well as the wind speed associated with each condition were presented on the x-axis. The associated amount of wear for each of those conditions were presented on the y-axis measured by weight in grams and given for each of the three selected W/C designated as M1, M2, and M3.

Analysis of the first condition of ambient air temperature of 15 °C and the condition of 35-kph-wind speed, the amount of wear associated with mix M1 (W/C = 0.30) for the field specimens are approximately 55 % more wear than the ideal specimen, this indicates a reduction in abrasion resistance caused by the effect of exposure above.

The value of the amount of wear for mix M2 (W/C = 0.45) also gives more wear for the field specimen compared to the ideal specimens with approximately 73% difference. This indicates a reduction in the abrasion resistance with more wear generated caused by the difference in W/C values. Same behavior can be noticed for mix M3 (W/C = 0.6) with more

wear in the field specimen of 80 % compared to that of the ideal specimen.

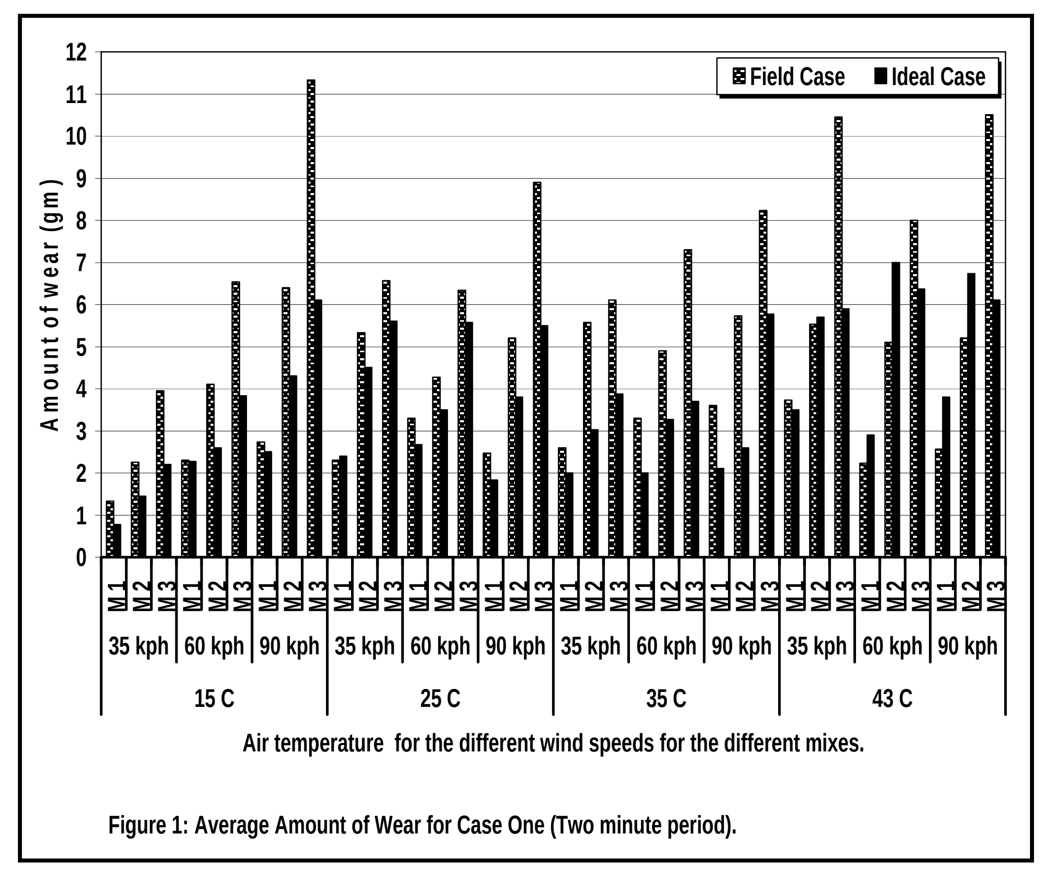


Figure 1: Average Amount of Wear for Case One (Two minute period).

Analysis of the same ambient air temperature condition for M1, M2, and M3, indicate that the leaner the mix the more the effect of wind speed on the reduction of abrasion resistance. In another word, as the loss of moisture increases as wind speed increase having the chemical reaction short of enough moisture to fully take place and eventually reduces strength of the surface layer. Analysis of the condition of 15 °C and wind speed of 60 kph, indicate the same behavior can be noticed but with more wear generated caused by the increase in wind speed which indicates higher evaporation rate.

For the same condition of an ambient air temperature of 15 °C but with a wind speed of 90 kph, the same behavior was noticed with further increase in the amount of wear or further decrease in abrasion resistance caused by higher loss of moisture from the fresh concrete surface. For all conditions of wind speed and an ambient air temperature of 15 °C, there was a significant decrease in abrasion resistance with the increase of wind speed.

It is important to note that each mix was prepared separately for each condition of air temperature and wind speed, but using same materials and mix proportions. For that reason, the comparative analysis is based on the difference in the amount of wear of each set of the field and ideal specimens.

Analysis of the ambient air temperature of 25 °C and the various wind speeds considered above were shown in Figure1, generally, the same behavior was repeated with minor change in the amount of wear between the three wind speeds for the same conditions of ambient air temperature of 15 °C and 25 °C. For example, the overall difference of wear for all wind speeds and different mixes used was +4.0 % of more wear for the 25 °C condition compared to that of 15°C condition, considering the nature of the test, this difference is considered insignificant. In general, the comparative analysis between the two conditions of ambient air temperature of 15 °C and 25 °C indicated no difference in abrasion resistance, which means that the difference in temperature in this range has no significant effect on the rate of loss of surface moisture for the same wind speed. Differences in wear for the three cases of wind speed were significant which means loss of surface moisture was consistent with that of the first condition of ambient air temperature which lead to the conclusion that in spit of temperature change within the range of 15-25 °C, differences in wear caused by change in wind speed is approximately the same for each case of wind speed.

Analysis of the ambient air temperature condition of 35 °C, indicated in this case too, the same behavior was noticed between the two

conditions of ambient air temperature of 15 °C, and 25 °C compared to that of the condition of 35 °C. The overall differences in percent of abrasion resistance were +3 % and –1 % respectively. Differences were insignificant considering the nature of the test. This indicates that within the range of 15-35 °C, ambient air temperatures have no significance on the abrasion resistance of Portland Cement concrete surfaces. As far as the different in wear between the three wind speeds used in this research, significant difference exists between each of these values of wind speeds irrespective of change in ambient air temperature.

Analysis of ambient air temperature of 43 °C indicated that the effect of wind speed was consistent with that of other temperature conditions considered except with higher amount of wear generated in each of the three conditions of wind speeds as shown in Figure 1. A comparative analysis of the overall difference in wear between the ambient air temperature conditions of 15 °C, 25 °C, and 35 °C to that of the 43 °C, the difference was +18 %, +14 %, and +15 % respectively, indicating more amount of wear generated for the 43 °C ambient air temperature condition. In another word, a significant reduction in abrasion resistance was noticed for the condition of 43 °C.

Analysis of all conditions considered for wind speed revealed that a significant reduction was noticed with increase in wind speed irrespective of water-Cement ratio or air temperature. Drastic reduction of abrasion resistance was noticed at wind speeds in excess of 60 kph. As far as air temperature conditions are considered, it was noticed that the effect of air temperature was only significant at relatively high temperatures in excess of 35 °C. The overall difference between field and ideal specimens was 115 % for all conditions of air temperature, wind speed, and concrete mixes.

Analysis of case two (extra two minutes of wear) for all conditions of ambient air temperature and wind speed for the three concrete mixes considered relative to the amount of wear generated is shown in Figure 2. It should be noticed that in this case too, all specimens tested in case one for the three values of wind speed and for values of ambient air

temperature, those were tested again on the same location for an extra two minutes. For the condition of 15 °C, the average difference in the amount of wear generated was 16 % for this case compared to approximately 69 % difference for the same condition in case one. This indicates that less difference in wear between ideal and field specimens or less wear was generated in the lower parts of concrete surfaces or the effect of exposure of wind speed and ambient air temperature was significantly less than that of the top surface.

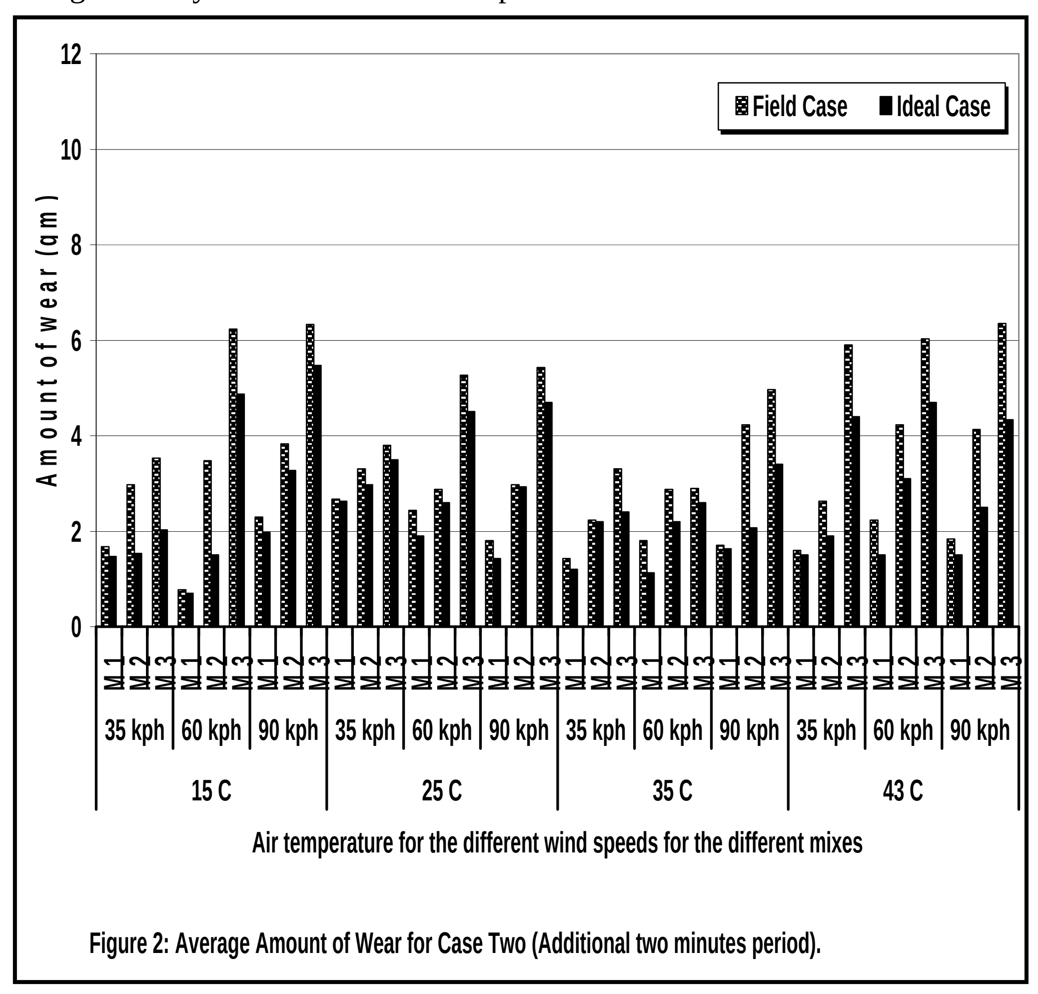


Figure 2: Average Amount of Wear for Case Two (Additional two minutes period).

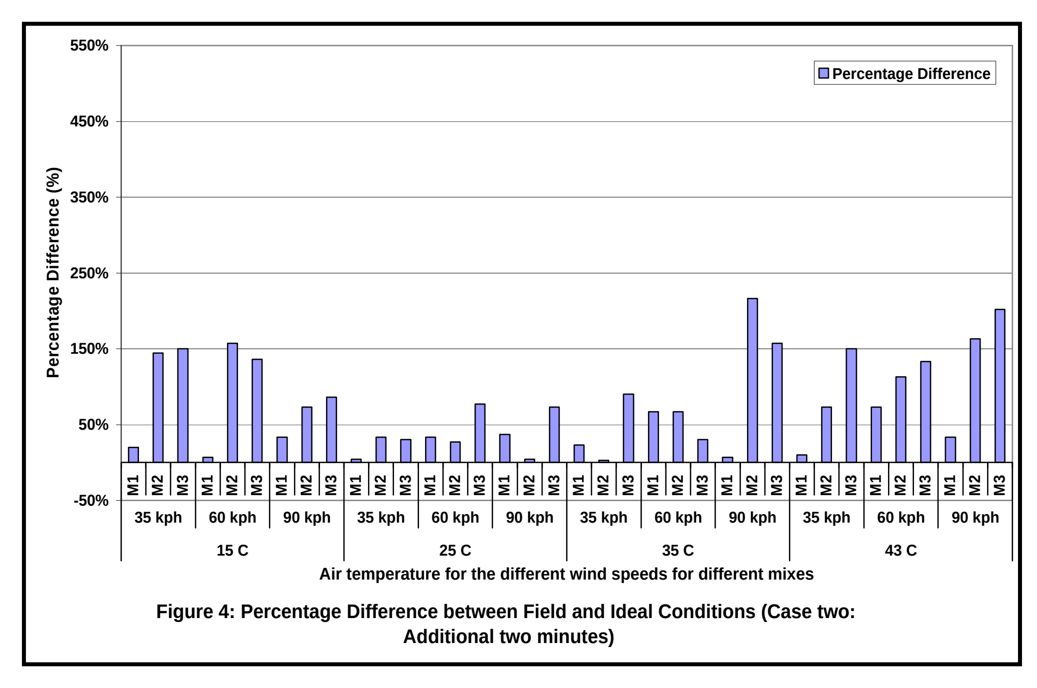


Figure 4: Percentage Difference between Field and Ideal Conditions (Case two: Additional two minutes)

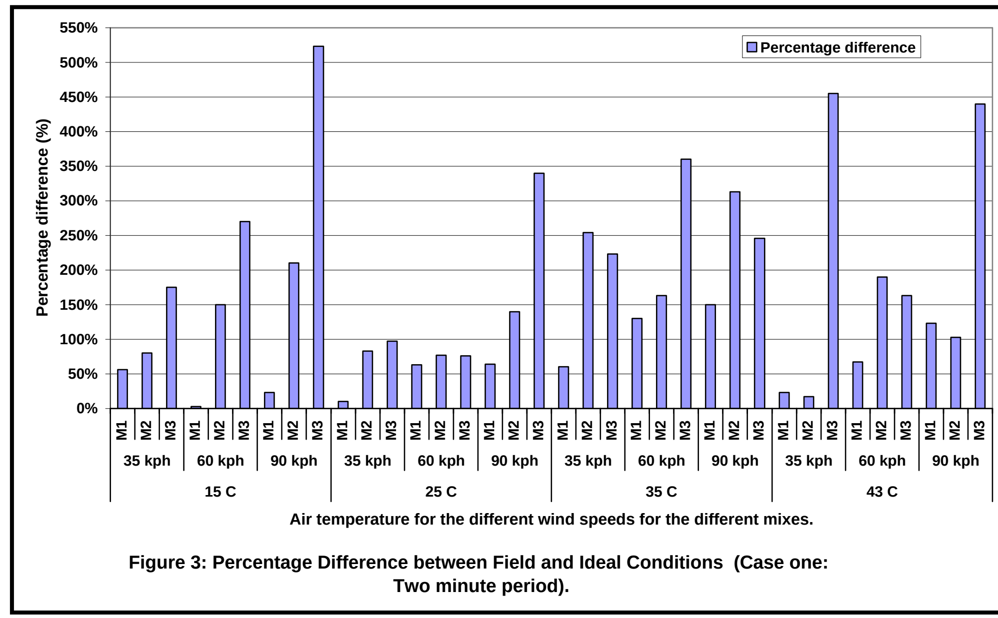


Figure 3: Percentage Difference between Field and Ideal Conditions (Case one: Two minute period).

Analysis of the difference in wear between field and ideal specimens for the other ambient air temperatures of 25 °C, 35 °C, and 43 °C for case two and those of case one, indicated that the difference of 63 %, 88 %, and 86 % respectively. Those differences are considered significant. The overall difference was 63 % between case one and two for all conditions of ambient air temperature and wind speed. This difference clearly indicates a significant effect of both air temperature and wind speeds by an excess amount of wear generated in case one relative to case two (less abrasion resistance) and eventually a drastic effect on durability of Portland Cement concrete surfaces.

Conclusions

Based on the results of this research, the following conclusions are considered valid:

1. Durability of fresh Portland Cement concrete surfaces was significantly affected by wind speed during the setting-time of concrete.
2. Abrasion resistance of fresh Portland Cement concrete was significantly affected as a result of temperature change at high temperature in excess of 35 °C.
3. In general, weather conditions of wind speeds in excess of 60 kph or and ambient air temperatures in excess 35 °C requires proper attention to ingredients, production methods, handling, placing, and curing of Portland Cement concrete.
4. The effect of air temperature and wind speed on the abrasion resistance of Portland Cement concrete was inversely proportional from the surface within concrete surface.

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List of notation

Notation	Definition
kg/cm^2	Kilogram per Centimeter Square
kg/m3	Kilogram Per Cubic Meter
mm	Millimeters
°C	**Degree Celsius**
Kph	Kilometers per hour
SSD	Saturated Surface Dry
°F	**Degree Fahrenheit**